The role of S_{11} resonance in πN Scattering

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Abstract

We analyze Pion Nucleon Scattering up to 700 MeV using a simple, relativistic, unitary model.[1] The kernel of the integral equation includes nucleon, roper, delta, D_{13} as well as S_{11} poles with their corresponding crossed pole terms approximated by contact interactions. The s- and p- wave phase shifts are calculated from the model and shown to agree very well with the values derived from πN scattering data.[2] All parameters which involve S_{11} are presented.

I. Introduction

Even though pion-nucleon scattering has been extensively studied for many years, there still remains a number of interesting problems to be explored, especially with the construction of powerful new facilities such as TJNAF (Thomas Jefferson National Lab) in Virginia, USA. In this brief paper we analyze pion nucleon scattering up to 700 MeV laboratory kinetic energy of pion using a simple, covariant and unitary model of πN scattering.[1]

In this work, the πN scattering amplitude is obtained as a solution of a relativistic wave equation in which the pion and eta is restricted to their mass shell in all intermediate states. The rationale for this approach has been discussed by Gross and Surya.[1] The kernel of the relativistic integral equation includes undressed delta (Δ),roper(N^*), D_{13} and S_{11} poles in addition to the undressed nucleon (N) pole. The kernel also includes contributions derived from crossed $N, \Delta, N*, D_{13}$,and S_{11} diagrams, as well as from σ- and ρ-like exchange terms. To keep the model simple the crossed terms are approximated by contact interactions as described in reference [1].

The πNN coupling is taken to be the superposition of both pseudoscalar and pseudovector coupling and the πNS_{11} coupling is taken as a superposition of both scalar and vector coupling. However for simplicity we take only scalar coupling for the ηNS_{11} coupling (the results obtained also show this tendency). The Feynman rule for the πNN and πNS_{11}vertex are given as follows,

$$\pi NN \quad \text{vertex}: \quad \Gamma_{0N} = g_{\pi NN}\left(\lambda + \frac{1-\lambda}{2m}\gamma^\mu k_\mu\right)\gamma^5\tau_i$$

$$\pi NS_{11} \quad \text{vertex}: \quad \Gamma_{0S} = i\left(g_1 + \frac{g_2}{m}\gamma^\mu k_\mu\right)\tau_i$$

$$\eta NS_{11} \quad \text{vertex}: \quad \Gamma_{0\eta} = i g_\eta \tau_0$$

k is the pion momentum, λ is a mixing parameter that is determined by the requirement that the nucleon mass be unshifted by the interaction,[1] g_1, g_2 and g_η are the coupling constants adjusted to fit data and m is the nucleon mass. The πNN coupling $g_{\pi NN}$ is chosen to be equal to 13.5 the same as in the reference [1].

II. The model

The model has been described in detail in reference [1] except for the S_{11} resonance. Figure (1) shows additional kernels that one needed to describe

Figure 1:

Figure 2:

the S_{11} resonance. Consistent with the previous model, the crossed diagram is approximated as a contact interaction.

Figure (2) shows the self energy of S_{11}. M_c is the infinite sum of iterated the contact diagrams. The $M_c^{\pi\pi}, M_c^{\pi\eta}, M_c^{\eta\pi}$ and $M_c^{\eta\eta}$ are treated as a coupled channel.

III. Results

Due to the contact interactions approximation, the model allows us to fit the spin $\frac{1}{2}$and spin $\frac{3}{2}$ phase shifts separately. Our fit to S_{11}, S_{31}, P_{11} and P_{31} phase shifts are given in Figures 3 and 4. The fit is good. The S_{11} phase shifts are particularly interesting. Figure 5 shows how the total is

built up from individual contributions, the curves in the figures show the result when the kernel (i) includes only the direct nucleon pole term and the contact term derived from crossed nucleon exchange *plus* the combined σ- and ρ- like contact terms (the dot line), (ii) the terms in (i) *plus* the additional ρ-like $\pi\pi NN$ contact term (the dot-dashed line), (iii) the terms in (ii) plus roper driving terms (dashed line) and finally (iv) the total result, which includes the terms in (iii) plus S_{11} driving terms (solid line).

From our calculation the contribution from S_{11} (including ηN channel) plays an important role to pion nucleon interaction at energies above 600 MeV as shown in Figure 5.

Table 1 shows parameters that are used to fit the data (column 2). The table includes effective masses (m) and widths (Γ) of the resonances (column 3) . In the table, Λ represents the baryon cut off mass, $g\prime$ is the inelastic coupling in the roper channel. We found the S_{11} width is smaller compared to Particle data group (∼100 to 250 MeV).[3] This maybe is related to our smaller value of $g_{\eta N S_{11}} = 1.19$ as compared to effective models results[3] or QCD sum rules using interpolating field results[4]which is around 2.

parameter	value	effective value
Λ	1205.8	
$\Lambda(N^*)$	1961.3	
$g_{\pi NN^*}$	6.924	
m_{N^*}	1458.0	1463.5
Γ_{N^*}		244.3
C_ρ	0.911	
$g\prime$	0.793	
g_2	1.910	
g_1	1.222	
Λ_{s11}	2666.3	
m_{s11}	1540.6	1567.0
Γ_{s11}		57.4
$g_{\eta NS_{11}}$	1.19	

IV. Conclusions

We have successfully extended the relativistic, simple and unitary model of pion nucleon scattering[1]to analyze the pion nucleon scattering up to 700 MeV which includes the S_{11} resonance. We find that the model works well despite of our meson on-shell approximation in all intermediate states. We also find that the inclusion of ηN channel tends to give the correct high energy

behavior. The coupling of pion and eta to the nucleon and S_{11} is smaller than expected. This would be clarified by some quark model calculations.

V. Acknowledgment

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Figure 3: S_{11} phase-shifts

Figure 4: P - wave phase shifts

Figure 5: S - wave phase shifts

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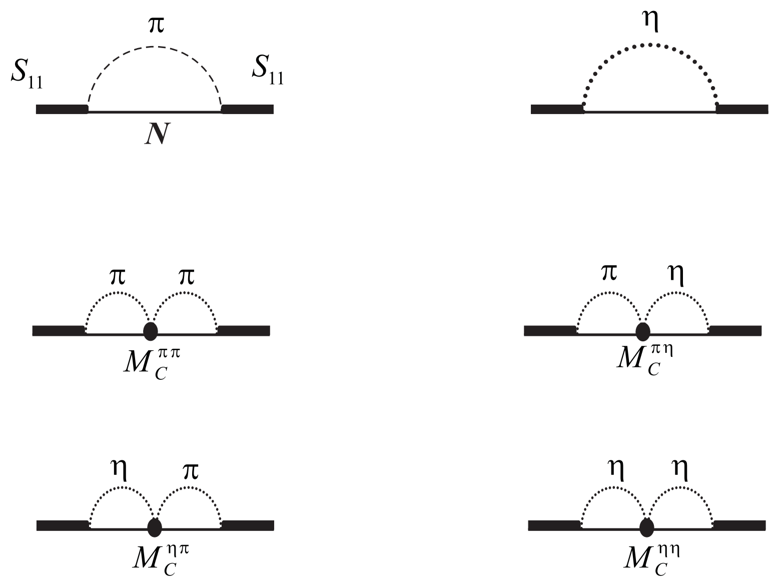
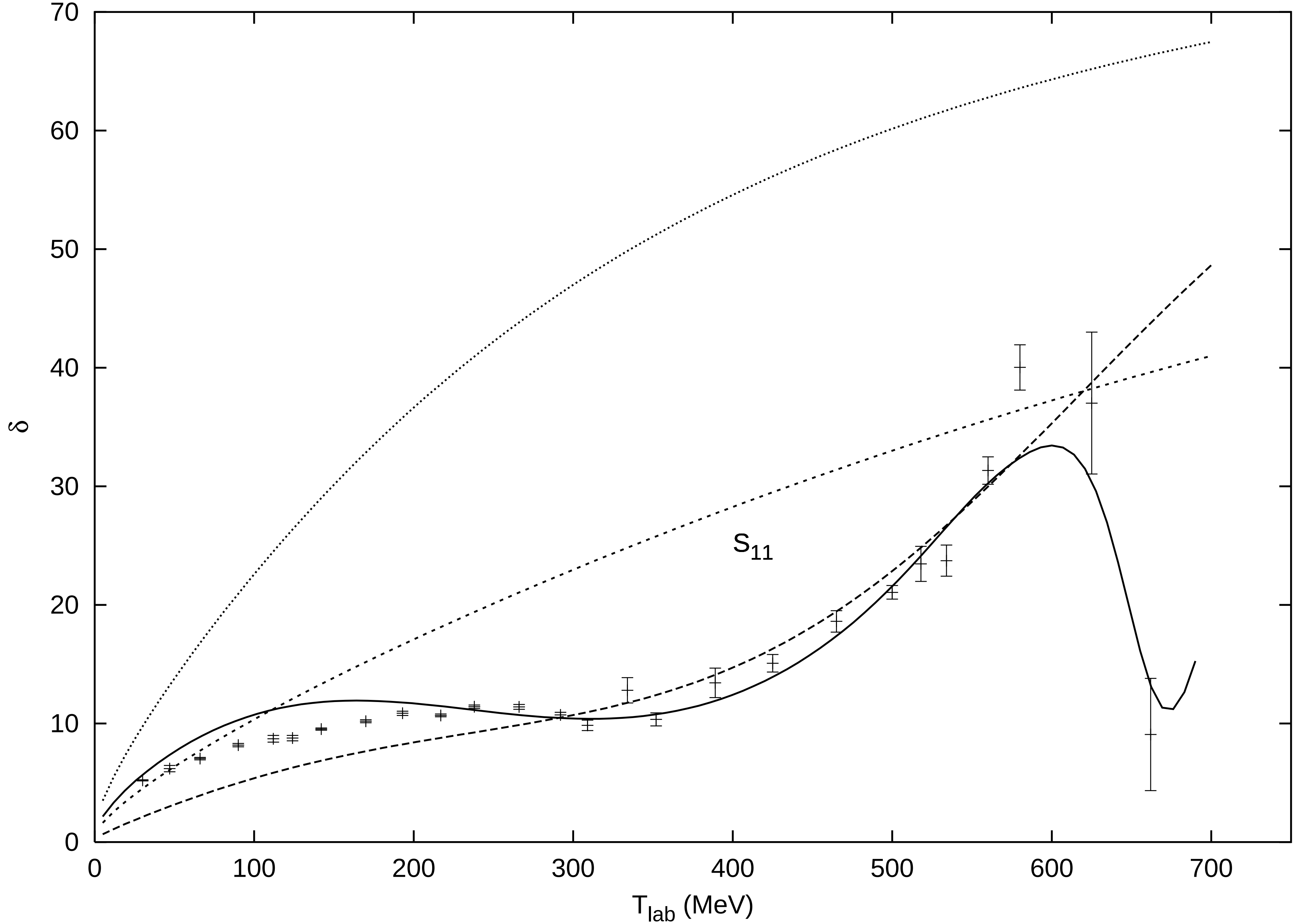
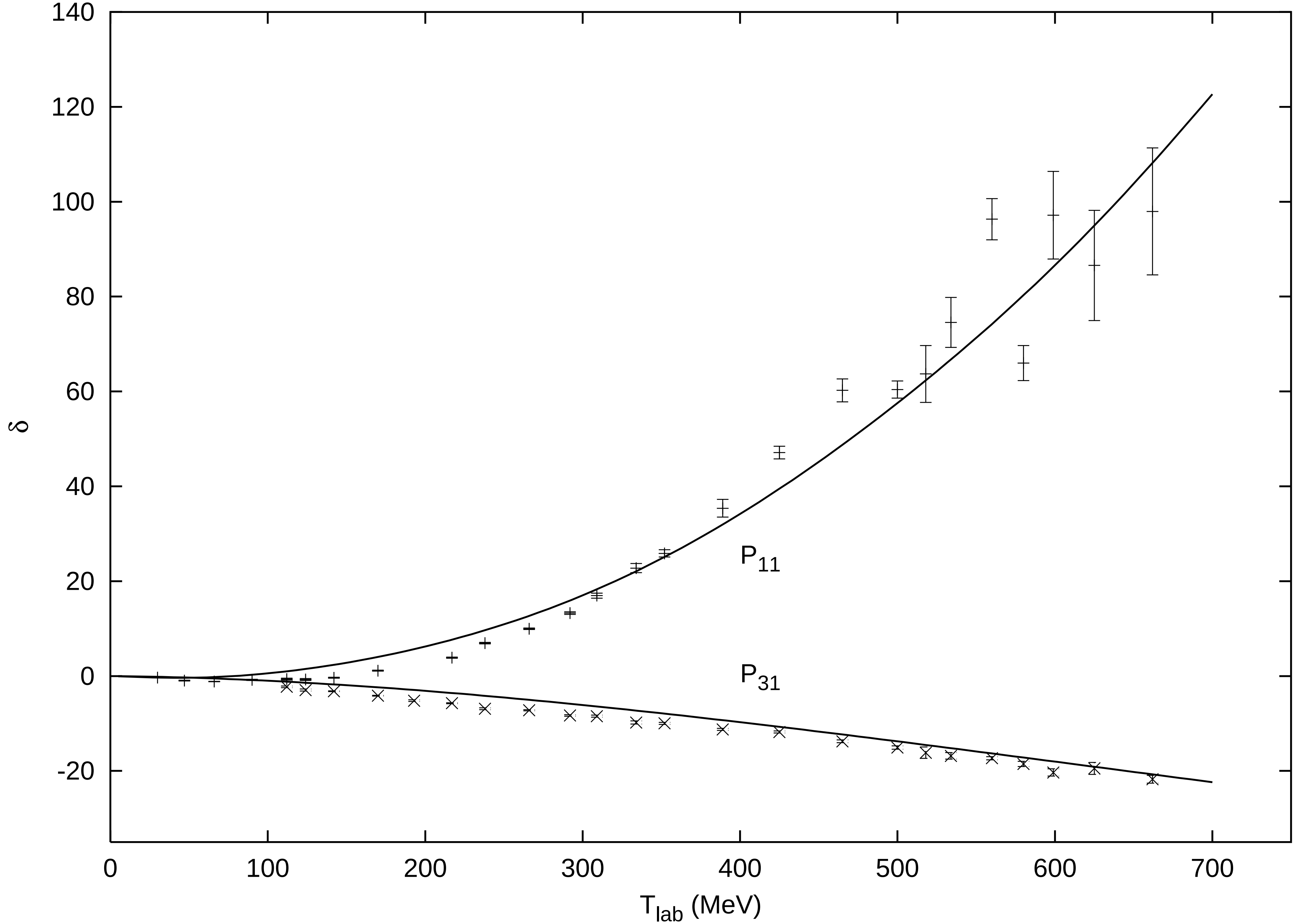
π
π
S_{11}
π
π
S_{11}



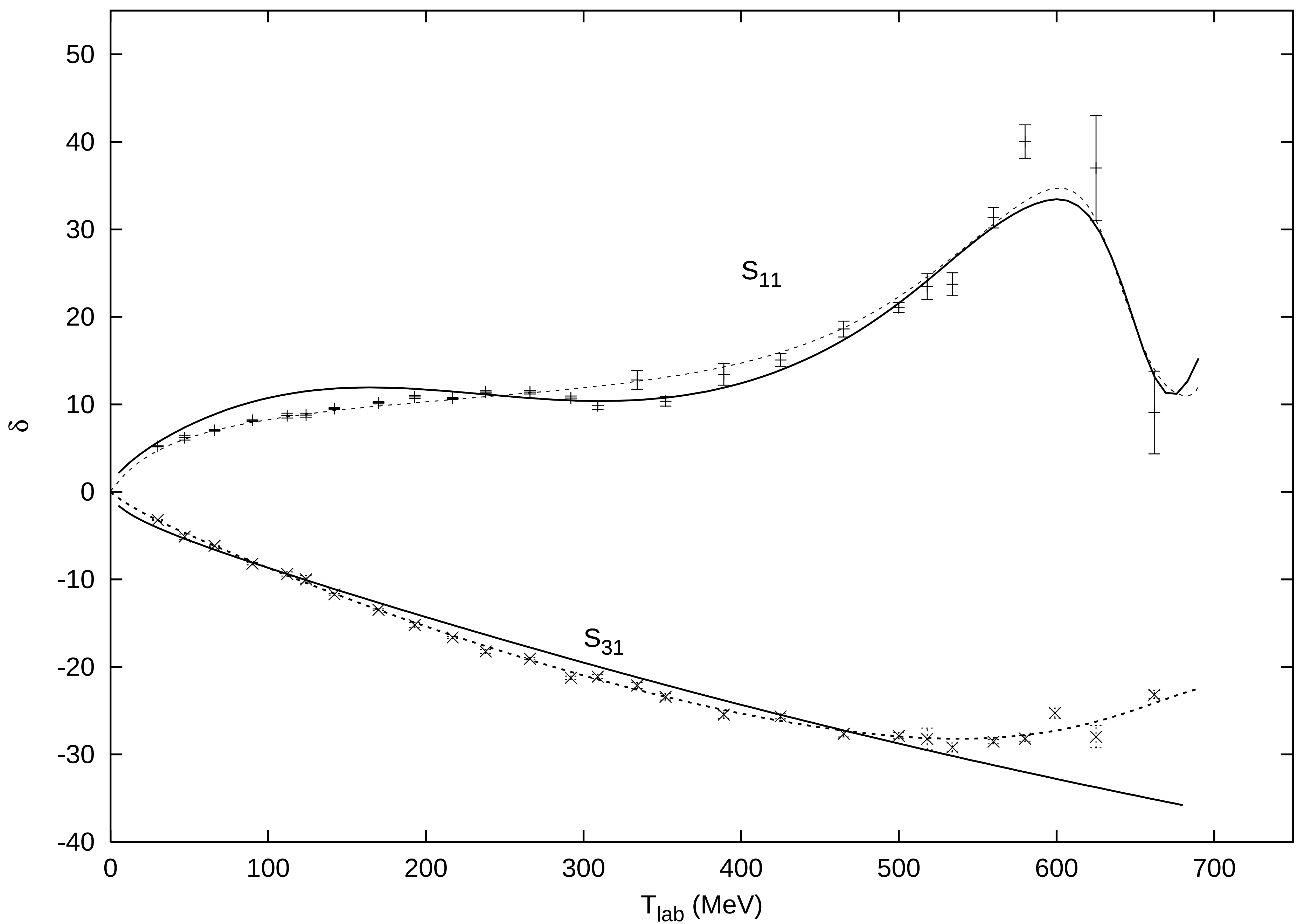
π
S_{11}
S_{11}
N
η
π π
$M_C^{\pi\pi}$
π η
$M_C^{\pi\eta}$
η π
$M_C^{\eta\pi}$
η η
$M_C^{\eta\eta}$



70
60
50
40
30
20
10
0
0
100
200
300
400
500
600
700
δ
T_{lab} (MeV)
S_{11}



140
120
100
80
60
40
20
0
-20
δ
P11
P31
0
100
200
300
400
500
600
700
Tlab (MeV)



δ
T_lab (MeV)
S11
S31
50
40
30
20
10
0
-10
-20
-30
-40
0
100
200
300
400
500
600
700